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Performance Design Study Based on the Spanish Building Regulation

R. A. González-Lezcano[1], J.B. Echeverría-Trueba[1], M. Arce-Blanco[2], S. Hormigos-Jiménez[1]

[1]Department of Architecture and Design, Universidad CEU San Pablo, Boadilla del Monte, Madrid, Spain
[2] Department of Structures, Universidad Politécnica de Madrid, Madrid, Spain
Email: *rgonzalezcano@ceu.es, jbecheverria@ceu.es, marina_arce@hotmail.com, sus.hormigos@ceindo.ceu.es.*

Abstract- This article presents a study of different housing blocks in the city of Madrid, in which effective interventions are carried out not only for energy savings within the requirements of the Technical Building Code in Spain also an installation saving in the short term. Various thicknesses of insulation types are analyzed, evaluating the resulting energy savings for each case but not without leaving aside the economic aspect of the installation; obtaining asymptotic values, in which the marginal cost of the investment will not be as variable. Interventions in lighting are analyzed and the reflection factors of the walls are also studied, showing different behaviors of energy expenses per square meters of housing, according to different types of luminaries and the lighting system chosen is presented. A study of the required ventilation levels and their impact on energy use is also made, depending on air quality desired levels taking into considerations different conditions of outdoor air quality. The article is a breakthrough in the study of alternative home energy saving and serving as a basis for performance design study in residential buildings.

Keywords: *Spanish Regulation; Sustainability; Energy efficiency; Energy consumption; Economic benefits; Construction methods.*

I. INTRODUCTION

This paper aims to analyse how the national regulations could focus on the ideas of “sustainability” or “energy efficiency” not only in new buildings but in existing ones. Ittries to give a response to the question: must energy saving measures be huge and equal interventions for every building or should they be small actions which can be designed according to the specific characteristics of each construction?

It reflects, by analysing several housing blocks, the need of new regulations which guarantee high levels of sustainability. Nowadays it would suppose significant economic benefits, considering the importance of monetary reinforcement desirable in the construction sector. This paper provides economic saving data based on the Spanish building regulation.

Usually, current regulation establish big interventions; at the contrary, this research paper shows small ones which contribute to high energy savings and low energy demand. This paper aims to demonstrate that current Spanish building regulations should be designed according to the geometric morphology, use, construction methods and others, following insulations and illumination factors. It has been concluded that those measures could consist of introducing insulation inside the air cavity of external walls, replacing internal partitions by cardboard planes, replacing the existing luminaries with low-consumption ones.

During the last decade, several actions have been taken in order to improve energy efficiency in buildings under construction. However, the challenge is reaching this objective in old constructions. Due to the establishment of the Spanish building regulation: Technical Building Code (TBC), compulsory in new buildings in Spain from 2006, a new situation has come out in the construction sector. TBC includes several actions to carry out in order to reach basic requirements for security and habitability. Those requirements can be found in the 5th of November Law 38/1999. TBC also contains measures to improve the accessibility in buildings according to the 2nd of December Law 51/2003 [1].

The objective is reaching sustainability and energetic saving providing several restriction norms to be applied in new buildings. Nevertheless, this commitment becomes a challenge in pre-existent constructions within an energy efficiency context.

[2] In Spain, since 1957, the so called MV regulations were the rules which must be followed by architects and engineers to design and carry out the construction of their buildings. Those rules were developed by the Architecture Department of the Interior Ministry, an institution founded in 1937. Forty years later, MV regulations turned into the NBE ones (Basic Edification Norms), because the Government decided to create a common directive related to the construction field, to which NTE non-compulsory regulations where added just as a complement for the others to guide builders to carry out the construction process. Finally, in 1999, it was published the National Building Regulation Law 38/1999 of the 5th of November, thus the Government was allowed to approve the Technical Building Code (TBC) by Royal Legislative Decree. Therefore, every requirement which must be comply by any building in Spain, according to security and habitability conditions, is included, since that date, in the Technical Building Code.

It would be necessary to establish a series of specific codes related to actions associated to the type of building, use, built surface, economy, efficiency, durability and others. Those measures would guarantee energy saving and and/or economical one depending on the construction surface, instead of demanding a series of actions without considering how they would perform [3].

It is commonly known that energy saving supposes economic benefits which are reached by reducing operating costs (by adopting passive solutions), reducing waste (by having major savings in construction and demolition costs) or by enhancing productivity and learning [4]. Another important factor for economic benefit is also the legislation, this aspect is shown in ‘Sustainable Construction’ by Sandy Halliday: ‘legislation is now a vital consideration as environmental bodies shows increased willingness to introduce and use the law to prevent poor environmental practice. Future-proofing is important as changes in regulatory requirements can have significant associated costs if they lead to major contract variations’ [5].

The adopted measures are significant because they have direct impact to the environment, thus they must be studied taking into account the most fields of knowledge as possible. In 1992, the UN Conference on Environment and Development (UNCED) or Rio Earth Summit brought together 170 heads of state and government. One of the main principles adopted by the Conference was the following: “where there are threats of serious or irreversible damage to the environment, lack of scientific certainty should not be used as a reason for postponing cost-effective measures to prevent environmental degradation” [6]. According to that, this paper tries to demonstrate that there are several measures that could be applied in order to achieve the best results in the energy saving field.

Finally, this paper successfully met the following objectives: to propose several measures to carry out in buildings in order to obtain low energy demand and demonstrate their viability and also to reconsider those measures to replace the ones outcome by TBC, which, in most cases, are so huge and generalized.

This paper shows several buildings with no specific insulation material (very common characteristic in buildings which were built in the first half of the 20th century in Spain). The energy demand is estimated and some improvements, in the energy saving field, are proposed.

Therefore, better results are obtained when applying the following measures:

- Insulation in walls
- Performance of Thermal Facilities
- Performance of Lighting Facilities

Improvements are shown comparing the results with the existing ones and with TBC regulations.

II. METHODS

Experimental work has been undertaken in several existing housing blocks, located in Madrid (Spain), trying to look for different alternatives in order to reach significant energetic saving. Taking into account some divisions of the TBC, it was possible to make a comparison between the information obtained from economy and energy savings.

It has been randomly chosen five old buildings with two common aspects: they do not have specific insulation materials and their total floor surfaces are not lower than 1500m2. Then it is possible to acquire the benefits and savings provided by the introduction of different variables that will be explained below. Horizontal structure is made by reinforced concrete in both slabs and hanging beams, whereas brick is used in external walls.

Based on the different sections of the TBC, a series of proposals in pre-existent building with refurbishment and reform targets were made.

The basic requirements established in the TBC with respect to limited energy demand is as follows: "The buildings will have an enclosure in such a way that it limits appropriately the required energy demand to achieve thermal comfort according to the local climate, the use of the building and the summer and winter patterns, as well as the characteristics of the insulation and thermal inertia, air permeability and solar radiation exposure, thus reducing the risk of superficial humidity and interstitial condensation that could damage their characteristics and trying properly thermal bridges to limit heat gains or losses and thus avoiding avoid hydrothermal problems in there." The energy demand function required by a building depends basically on factors more or less complicated, outlined in the following table:

Table 1. *Energy demand factors.*

Factors	**Definition**
Climatology	Climatic zone
Enclosure quality	Hydrothermal study
Functional characteristics	Project
Energy system	Project

Therefore, the improvements in external walls, it would guarantee, throughout the time, consumption savings and a reduction of harmful emissions [7].

This paper studies the influence of the insulation capacity: the maximum thermal resistance of the external walls and internal partitions, as well as façade wall openings.

It has been studied the energy demand in the building, therefore, the alternative procedure of the simplified option has been applied, which is based on an indirect control by limiting the thermal parameters of the building envelope. For this purpose, it has been made a comparison between the values obtained during calculation and those values that would be obtained modifying the thermal envelope conditions. According to the results obtained, some improvements are shown in order to reduce both surface condensation risk (inside walls) and energy demand (because of air infiltration).

The characteristic parameters studied are:

- Thermal transmittance of façade walls (UM)
- Thermal transmittance of openings (UH)

The TBC indicates the transmittances of constructive elements in relation to the building location. The case study buildings are located in Madrid, therefore the climatic area (as it is shown in TBC) is D3 and the limit values to be considered are the following:

- Maximum transmittance of façade walls and walls in contact to the ground UMlim:0.66 W/m^2K
- Maximum transmittance of the ground: USlim: 0.49 W/m^2K
- Maximum transmittance of roofs: UClim: 0.38 W/m^2K
- Maximum modified solar factor: ULlim: 0.28

Thermal transmittance U (W/m2K) is given by the following expression: U=1/RT

In the last expression, RT is the total thermal resistance of the constructive element (m^2 K / W). When the constructive element is made by layers thermally homogeneous, it must be calculated as follow:

$$R_T = R_{si} + R_1 + R_2 + \cdots + R_n + R_{se}$$

Where R_1, R_2, R_n are the thermal resistance of each layer, and Rsi is the superficial thermal resistance of indoor air and Rse of the outdoor air, according to the position of the enclosure, direction of the air flow and building location. In the proposed case study building, it has been considered the following parameters: R_{se} = 0.04 m^2·K/W and Rsi = 0.13 m^2·K/W, because the enclosure is vertical (or it has a slope over the horizontal plane higher than 60º).

The thermal resistance of a layer thermally homogeneous layer is defined by the expression: R = e / λ

In the last expression 'e' corresponds to the thickness of the layer (m). In case of variable thickness, it would be considered the average thickness. λ is the thermal conductivity of the layer material obtained from the thermal values included in the norm UNE EN ISO 10 456:2001[8].

Improvements in both economic and energetic saving are obtained by introducing different insulation thicknesses in the building walls and internal partitions (plasterboard panel) or by using different types of double glaze with air gaps of 6.9 and 12 mm.

III. RESULTS AND DISCUSSIONS

There are three possibilities to introduce insulation in the building envelope:

- On the outdoor surface
- Integrated within the wall
- On the indoor surface

It is known that insulation must be placed on the hot or cold side of the protected space, and also in façades. There are different ways to be considered about insulation placement [9], those are the following:

- When locating on the external face, the wall would absorb inner energy. On the one hand diminishing energy consumption decreases. On the other hand the cost of installation is higher due to the high thermal inertia.
- When placing insulation integrated in external walls. This would perform as a thermal barrier between external and internal flows. The insulation cost could be compensated by means of the starting and during the permanent functioning of the heating system. According to that, the comfort sensation is almost immediate.
- Insulation located on the internal face of the wall generates a very low thermal inertia with immediate results. The cost of the start-up and the permanent functioning of the heating system are low and the comfort sensation is immediate.

In case of refurbishment and knowing the efficiency when introducing insulation, the best options could come when introducing insulation either integrated within the enclosure wall or on the internal face. However, each situation has a disadvantage related to the construction process. If introducing insulation in an integrated manner, the problem would be how to do it, may be by drilling or rebuilding the inner wall. The costs would be high and the solution would not be possible. On the one hand, in case of introducing insulation on the inner layer the only problem would come from the fact that the apartments would lose floor area; therefore, it would be the most effective one. This solution (insulation in walls) avoids heat losses in the building rooms and so, the performance of the installation becomes more effective. On the other hand, it exists some advantages of external wall insulation over internal wall insulation; for example, and as general aspects, there is a reduced risk of condensation between the insulation layer and the masonry wall, the building fabric remains dry and heated from the interior and there is no impact on internal finishes and room sizes [10]. In terms of the finishing for external wall insulation, the main render options usually are silicone or mineral based as both of them are vapour permeable; even though, they have some differences: on the one hand, mineral render has higher level of permeability and fast setting; on the other hand, silicone render has huge flexibility but it should not be used when the air temperature is at or below 5ºC or when it is raining, that is why the most used technique usually is mineral render [11].

A. Insulated thickness

It has been conclude that the procedure that generates more savings consists of replacing windows with others with air gaps of at least 6 mm, because they are the areas with the largest heat losses (thermal bridges). It should be taken into account that whenever insulation is added to an existing building there is a danger of creating thermal bridges at critical points where the coverage may be interrupted [12].

In old buildings where windows have not been replaced; the openings are the places with more energy losses in the external walls. The replacement of supporting walls of internal partitions is more complicated, and then, savings become lower.

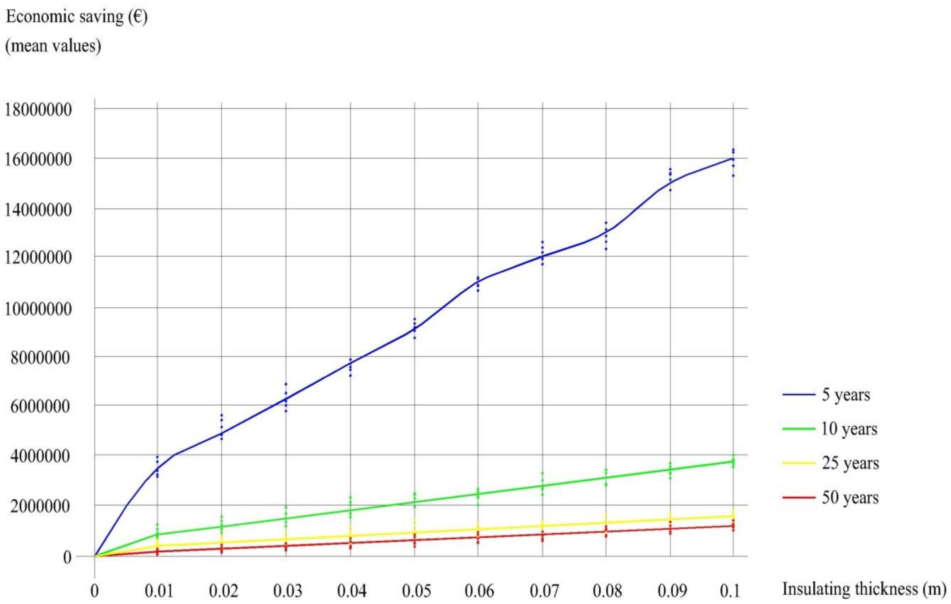


Figure 1. *Economic saving in 5, 10, 25 and 50 years by replacing internal brick by plasterboard panels*

It has been studied different cases with an insulated thickness of 0.01m, 0.020m, 0.030m, 0.040m, 0.050m0.060m, 0.070m, 0.080m, 0.090m and 0.1m.

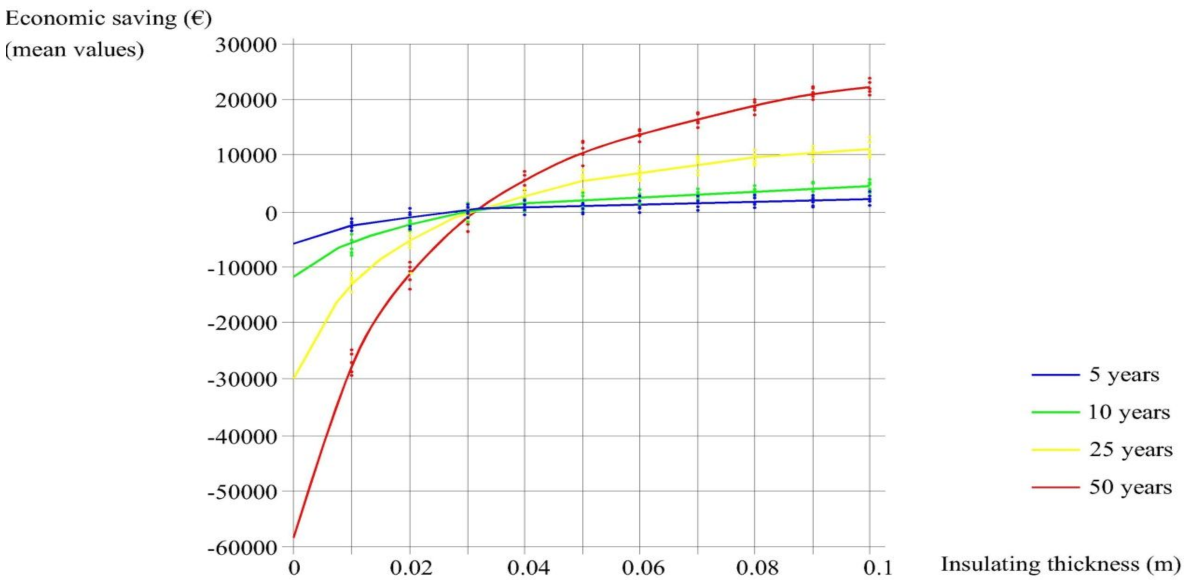


Figure 2. *Economic saving in 5, 10, 25 and 50 years by filling the external wall cavity with insulation*

It has been studied different cases with an insulated thickness of 0.01m, 0.020m, 0.030m, 0.040m, 0.050m0.060m, 0.070m, 0.080m, 0.090m and 0.1m.

The main objective of this section is to achieve an improvement in the thermal behaviour of the building envelope, so getting a maximum thermal resistance in the case study building envelope, both in walls and windows.

In developed countries, Heating, Ventilating and Air Conditioning (HVAC) consumes 40% of the energy expenditure. To minimize this cost, a sustainable architecture is being established, which brings new technologies able to control the energy of a building. Using active and passive systems it is reached several improvements in the behaviour of the building without increasing the construction cost.

As it has been shown, one of the easiest ways of saving energy is by increasing the insulation thickness in external or internal walls (figure 3). The higher the thickness is, the lower the transmittance.

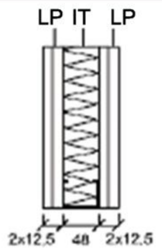
Internal partition		
Freestanding lattice		
LP Laminated Plaster Board SP 10mm MS 0.6mm thick Metallic Sheet IT Insulation: Mineral wool with air flow resistivity r≥5kPa.s/m^2		
Code	Section	HE U (W/m^{2}K)
P4.2		1/(0.46+RAT)

Figure 3. *Example of internal partition insulation*

Energy saving is calculated by the following expressions:

$$\Delta \mathrm{Q}\ (\%) = (\mathrm{Q} - \mathrm{Q}_o) \cdot 100$$

$$\mathrm{Q}_o\ (\mathrm{W}) = \mathrm{U}_o \left(\frac{W}{m^2 {}^\circ K}\right) \cdot S(m^2) \cdot \Delta\mathrm{T};\ \mathrm{Q(W)} = U\ \left(\frac{W}{m^2 {}^\circ K}\right) \cdot S(m^2) \cdot \Delta\mathrm{T}$$

$$\mathrm{U} = \left[\lambda \left(\frac{W}{m {}^\circ K}\right) \cdot \mathrm{U}_o \left(\frac{W}{m^2 {}^\circ K}\right)\right] / [\lambda \left(\frac{W}{m {}^\circ K}\right) + e(m) \cdot \mathrm{U}_o \left(\frac{W}{m^2 {}^\circ K}\right)]$$

$$\Delta \mathrm{Q}\ (\%) = \left(\frac{(\mathrm{e} \cdot \mathrm{U}_o)}{\lambda + e \cdot \mathrm{U}_o}\right) \cdot 100$$

Where,

ΔQ is heat loss

U is the thermal transmittance

ΔT is the indoor-outdoor thermal gap

With the last expression it is developed the following tables (table 2.1. and 2.2.) which shows, according to different insulation thicknesses and type, the corresponding energy saving which depends on the layer thickness (mm) and thermal conductivity λ (W/mK) of several types of insulation.

Table 2.a. *Energy saving according to different insulation types.*

ΔQ (%)	λ (W/mºK)									
Type			XPS [1]			PUR o PIR[7]				
Class	EPS[1]	EePS[2]	CO_2[4]	HFC[5]	MW[6]	HFC[8]	CO_2[9]	HFC p[10]	HFC i[11]	I CO_2[12]
Thickness (mm)	0.034	0.042	0.036	0.034	0.045	0.028	0.034	0.029	0.025	0.04
2.5	13.78	11.46	13.12	13.78	10.78	16.25	13.78	15.78	17.86	11.96
5	24.22	20.56	23.19	24.22	19.46	27.96	24.22	27.26	30.30	21.37
7.5	32.41	27.96	31.17	32.41	26.60	36.80	32.41	35.99	39.47	28.96
10	39.00	34.11	37.65	39.00	32.57	43.71	29.00	42.84	46.51	35.21
12.5	44.42	39.28	43.01	44.42	37.65	49.25	44.42	48.37	52.08	40.45
15	48.49	43.71	47.53	48.96	42.02	53.80	48.96	52.93	56.60	44.91
17.5	52.81	47.53	51.38	52.81	45.81	57.60	52.81	56.74	60.34	48.75
20	56.12	50.86	54.70	56.12	49.14	60.83	56.12	59.99	63.49	52.08
22.5	58.99	53.80	57.60	58.99	52.08	63.60	58.99	62.78	66.18	55.01
25	61.52	56.41	60.15	61.52	54.70	66.00	61.52	65.21	68.49	57.60
27.5	63.75	58.74	62.41	63.75	57.05	68.10	63.75	67.34	70.51	59.91
30	65.73	60.83	64.43	65.73	59.17	69.96	65.73	69.22	72.29	61.98
32.5	67.51	62.72	66.25	67.51	61.09	71.62	67.51	70.90	73.86	63.85
35	69.12	64.43	67.88	69.12	62.84	73.10	69.12	72.40	75.27	65.54
37.5	70.57	66.00	69.37	70.57	64.43	74.43	70.57	73.76	76.53	67.08
40	71.89	67.43	70.72	71.89	65.90	75.64	71.89	74.99	77.67	68.49
42.5	73.10	68.75	71.96	73.10	67.25	76.74	73.10	76.11	78.70	69.79
45	74.21	69.96	73.10	74.21	68.49	77.75	74.21	77.13	79.65	70.98

(1) Expanded Polystyrene (EPS)

(2) Elasticized Expanded Polystyrene (EEPS)

(3) Extruded Polystyrene

(4) Expanded with CO_2

(5) Expanded with HFC

(6) Mineral Wool (MW)

(7) Polyurethane (PUR) rigid foam or Polyisocyanurate (PIR) rigid foam

(8) HFC Projected

(9) CO_2 Projected

(10) Hydrofluorcarbon or hydrocarbon sheet and gas permeable coating

(11) Hydrofluorcarbon or hydrocarbon sheet and gas impermeable coating

(12) Injection in partitions with CO_2

Table 2.b. *Energy saving according to different insulation types.*

ΔQ (%)	λ (W/mºK)					
Type	Others (1)					
Class	Clay (2)	EPB (3)	CG(4)	FP(5)	PR(6)	PnR(7)
Thickness (mm)	0.122	0.062	0.05	0.036	0.059	0.039
2.5	4.26	8.06	9.80	13.12	8.43	12.23
5	8.18	14.92	17.86	23.19	15.56	21.80
7.5	11.79	20.82	24.59	31.17	21.65	29.48
10	15.12	25.96	30.30	37.65	26.93	35.79
12.5	18.22	30.47	35.21	43.01	31.53	41.06
15	21.09	34.47	39.47	47.53	35.60	45.54
17.5	23.77	38.03	43.21	51.38	39.20	49.38
20	26.27	41.22	46.51	54.70	42.43	52.71
22.5	28.62	44.10	49.45	57.60	45.33	55.64
25	30.82	46.71	52.08	60.15	47.95	58.22
27.5	32.89	49.09	54.46	62.41	50.33	60.52
30	34.84	51.26	56.60	64.43	52.50	62.58
32.5	36.67	53.26	58.56	66.25	54.49	64.43
35	68.41	55.10	60.34	67.88	56.32	66.11
37.5	40.06	56.80	61.98	69.37	58.01	67.64
40	41.61	58.38	63.49	70.72	59.58	69.04
42.5	43.09	59.84	64.89	71.96	61.03	70.32
45	44.50	61.21	66.18	73.10	62.38	71.50

(1) Other insulation materials

(2) Expanded clay

(3) Expanded perlite panel (EPB) (>80%)

(4) Cellular glass panel (CG)

(5) Polyester felt

(6) Reticulated polystyrene foam

(7) Non-reticulated polystyrene foam

It is shown (in tables 2.1. and 2.2.) the increase of energy saving until it reaches a value in which it reaches a value where it is not useful to continue the increase of the thickness because the saving variation rate per additional thickness (mm) is mainly negligible. If the thickness cannot be modified, tables 2.1 and 2.2 show which is the most appropriate insulation taking into account the project decisions or the energy efficiency.

B. Performance of Thermal Facilities

The Spanish regulation of thermal installations in buildings, RITE, aims to establish the conditions required by thermal installations to cover thermal comfort demands and hygiene through heating, air conditioning and hot water systems.

Everything is made with the objective of achieve a rational use of energy consumption, with both economic and environmental considerations, and taking into account other essential requirements during a reasonable period of time.

To improve indoor air quality, several easy options can be followed such as reducing bot carpet surface and the number of smokers and depending firstly on the quality of external air, an improvement of internal air is obtained.

The quality of external air is essential in the excellence of internal air. For a minimal internal air quality, external air does not intervene at all. As it happens with carpet surfaces, a 63 % of wool and 33 % of fibres is allowed in the studied are without affecting internal air quality.

It can be concluded that in order to improve indoor air quality the most appropriate solution is reducing the surface of carpeting, or locating buildings in an environment with an excellent air quality.

With the next expression, the necessary ventilation flow can be determined:

$$\mathrm{V} = \mathrm{F}/(\mathrm{C}_{int} - \mathrm{C}_{ext})$$

Where,

Cint is inner concentration

Cext is outdoor concentration

F is contamination (olf)

V is air flow (litres/second)

Taking 1 olf is the equivalent to the emission of odour of a non-smoker “average adult” who takes 0.7 baths a day, sitting and with 1.8 m^2 of skin.

From olf, decipol is defined as the air quality in a space with a source of pollution with strength of 1 olf, ventilated 10 L/s of fresh air, according to the Danish professor P. Ole Franger.

According to the regulation UNE-CR 1752 IN, the amount of pollution per occupant and under certain types of furniture and local materials can be set (table 3).

Table 3. *Amount of pollution per occupant, furniture and construction materials*

Sedentary occupants (1-1.2 met)	Olf/occupant
0% smokers	1
20% smokers	2
40% smokers	3
60% smokers	6
1 Athlete	30 olf
1 Smoker	25 olf
Wool carpets	0.2 olf/m^2
Fiber carpets	0.4 olf/m^2
PVC	0.2 olf/m^2

UNE-CR 1752 IN also establishes the outdoor air quality according to the air conditions; therefore, indoor air quality can be classified taking the according to the decipols in the indoor space (table 4).

Table 4. *Decipols and air conditions*

Quality (decipol)	Air conditions
100	Vent
10	Old buildings
1	Healthy buildings
0.2	Good city outdoor air quality
0.1	Excellent city outdoor air quality
0.01	Mountain outdoor air

Indoor air quality can be also classified according to the percentage of unsatisfied in indoor spaces (table 5).

Table 5. *Decipols and percentage of unsatisfied*

Indoor air quality	Unsatisfied (%)	Decipols
High	10	0.6
Standard	20	1.4

Minimum	30	2.5

Once known the necessary air flow for ventilation according to the amount of pollution, the cost in euros can be established. Figure 4 gives a comparison between the amount of saving that could be obtained depending on the situation. If there are no smokers in the space, it can be seen that having a bad outdoor air quality can multiply per 4 the ventilation costs if a high indoor air quality is needed.

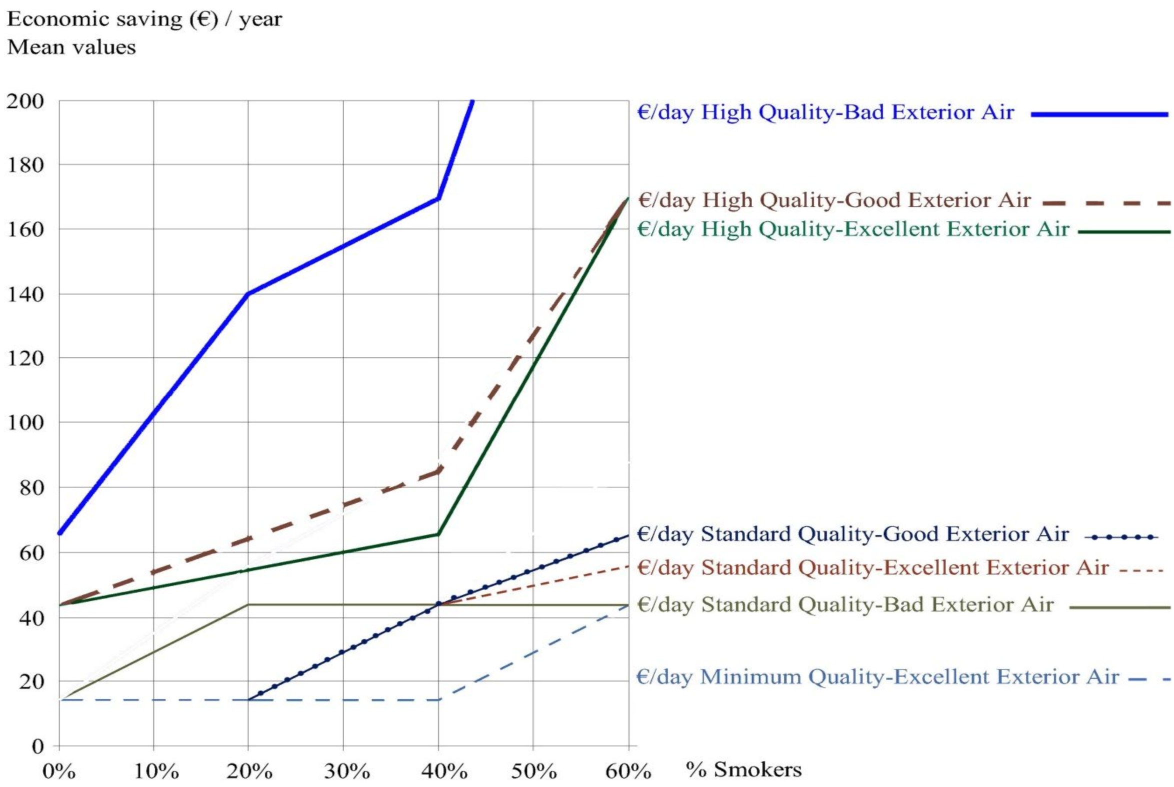


Figure 4. *Economic saving depending on the quality of external and internal air*

C. Energy efficiency of Lighting Facilities

According to the basic requirements associated to the efficiency of illumination systems, TBC establishes buildings which have adequate lighting facilities adapted to users' needs and at the same time energetically efficient as they provide a control system that allows the adjustment of the ignition to the actual occupation of the area, as well as a regulatory system that optimizes the use of natural light in areas with appropriate conditions.

By substituting the types of lamps it will be minimized the economic cost without decreasing their efficiency. Electric lighting is the source with higher energy consumption; however enormous energy savings are possible using energy efficient equipment, effective controls and careful design. Using less electric lighting reduces heat gain, thus saving air-conditioning energy and improving thermal comfort [13].

After analysing three types of luminaries: Steam High Pressure Sodium, Fluorescent and Fluorescent suspended grid, directly and indirectly, it is observed that the better the illumination the lower the energy power.

The values used to calculate the parameters related to each type of luminary are shown in the following tables:

Table 6.a. *Sodium Vapour High-pressure Luminaries.(P:400W; luminous flow:50000lm)*

Type of Lighting Fitting: Sodium Vapour High-pressure Luminaries P=400W luminous Flow=50000 lm											
	Utilization factor (η)										
	Ceiling reflection factor										
k	0.8			0.7			0.5			0.3	0
	Walls reflection factor										
	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.00
0.6	0.66	0.62	0.60	0.66	0.62	0.60	0.65	0.62	0.59	0.62	0.9	0.58
0.8	0.75	0.71	0.68	0.75	0.71	0.68	0.74	0.71	0.68	0.70	0.68	0.67
1.0	0.80	0.76	0.73	0.80	0.76	0.73	0.79	0.76	0.73	0.73	0.73	0.72
1.2	0.85	0.81	0.80	1.85	0.81	0.80	0.84	0.81	0.78	0.80	0.78	0.77
1.5	0.88	0.96	0.82	0.88	0.85	0.82	0.88	0.84	0.82	0.84	0.82	0.81
2.0	0.94	0.90	0.88	0.93	0.90	0.88	0.92	0.89	0.87	0.88	0.87	0.85
2.5	0.96	0.93	0.92	0.96	0.93	0.91	0.94	0.92	0.90	0.91	0.89	0.88
3.0	0.99	0.95	0.94	0.98	0.95	0.93	0.96	0.94	0.92	0.93	0.91	0.89
4.0	1.01	0.99	0.96	1.00	0.98	0.96	0.98	0.97	0.95	0.95	0.94	0.92
5.0	1.02	1.01	0.99	1.01	1.00	0.98	1.00	0.98	0.97	0.97	0.96	0.94
	$D_{max}=0.7H_m$							Fm.70.75.80				

Table 6.b. *Sodium Vapour High-pressure Luminaries (P=40W luminous flow=2520 lm)*

Type of Lighting Fitting: Sodium Vapour High-pressure Luminaries P=40W luminous Flow=2520 lm											
	Utilization factor (η)										
	Ceiling reflection factor										
k	0.8			0.7			0.5			0.3	0
	Walls reflection factor										
	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.00
0.6	0.3	0.26	0.25	0.29	0.26	0.23	0.29	0.26	0.23	0.25	0.23	0.22
0.8	0.36	0.32	0.29	0.35	0.32	0.29	0.35	0.31	0.29	0.31	0.29	0.27
1.0	0.43	0.40	0.37	0.43	0.40	0.37	0.42	0.39	0.37	0.39	0.37	0.36
1.2	0.47	0.44	0.42	0.47	0.44	0.41	0.46	0.43	0.41	0.43	0.41	0.40
1.5	0.50	0.47	0.44	0.50	0.47	0.44	0.49	0.46	0.44	0.46	0.44	0.43
2.0	0.53	0.50	0.49	0.53	0.50	0.48	0.51	0.50	0.48	0.49	0.47	0.46
2.5	0.55	0.53	0.51	0.55	0.53	0.51	0.54	0.52	0.50	0.51	0.50	0.49
3.0	0.57	0.54	0.53	0.56	0.54	0.52	0.55	0.53	0.51	0.52	0.51	0.50
4.0	0.59	0.57	0.55	0.58	0.56	0.55	0.56	0.55	0.54	0.54	0.53	0.52
5.0	0.60	0.58	0.57	0.59	0.57	0.56	0.57	0.56	0.56	0.56	0.54	0.53
$D_{max}=0.8H_m$						Fm.65.70.75.						

Table 3.c. *Sodium Vapour High-pressure Luminaries (P=60W luminous flow=4600 lm)*

Type of Lighting Fitting: Sodium Vapour High-pressure Luminaries P=60W luminous Flow=4600 lm					
	Utilization factor (η)				
	Ceiling reflection factor				
k	0.8	0.7	0.5	0.3	0
	Walls reflection factor				

	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.00
0.6	0.2	0.16	0.13	0.20	0.16	0.13	0.19	0.16	0.13	0.15	0.13	0.12
0.8	0.25	0.22	0.18	0.25	0.20	0.18	0.23	0.19	0.17	0.19	0.17	0.16
1.0	0.37	0.27	0.24	0.30	0.26	0.23	0.28	0.24	0.22	0.22	0.21	0.18
1.2	0.35	0.31	0.28	0.34	0.30	0.28	0.30	0.28	0.26	0.26	0.24	0.21
1.5	0.37	0.33	0.30	0.36	0.32	0.29	0.32	0.30	0.27	0.27	0.25	0.23
2.0	0.42	0.38	0.35	0.40	0.37	0.34	0.37	0.33	0.31	0.31	0.29	0.25
2.5	0.44	0.31	0.39	0.42	0.40	0.37	0.39	0.36	0.34	0.33	0.32	0.27
3.0	0.47	0.44	0.41	0.45	0.42	0.40	0.40	0.38	0.36	0.34	0.33	0.28
4.0	0.50	0.47	0.45	0.47	0.45	0.43	0.42	0.40	0.39	0.36	0.35	0.29
5.0	0.51	0.49	0.47	0.49	0.47	0.47	0.43	0.42	0.40	0.39	0.36	0.30
			D_{max}=0.8H_m						Fm.65.70.75.			

Depending on the type of luminary, power, energy efficiency value, use factor, reflection factor depending on the wall and ceiling colours, and its lifetime, the performance of the three types of luminaries (previously exposed) has been studied.

It is important to know that the energy efficiency of a lighting installation in a determined zone is established by the Value of Energy Efficiency, VEEI, and measured in W/m2 per 100 lux using the following expression:

$$\mathrm{VEEI} = (\mathrm{P} \cdot 100)/(\mathrm{S} \cdot E_m)$$

Where:

P: total power installed in lamps plus auxiliary equipment (W)

S: illuminated surface (m2)

E_m: medium horizontal illuminance (lux)

Considering the table 2.1., located in the TBC (CTE-DB-HE3: Energy Saving Basic Document in TBC), for floor areas in communal spaces, the current value for VEEI must be 6W/m^2 (it was 7.56W/m^2 in previous TBC).

Without exceeding the light levels indicated in TBC

Table 7. *Maximum installed power*

Use of the building	**Maximum installed power (W/m^2)**
Administrative	12
Parking	5
Commercial	15
Educational	15
Sanitary	15
Restoration	18
Auditory, theatre, cinema	15
Public residential	12
Others	10
Buildings with a lighting level above 600 lux	25

VEEI values are shown in the next table of the TBC

Table 8. *VEEI according to different areas of activity*

Differentiated activity areas	**Limit of VEEI values**
Administrative	3.0
Transport platforms stations	3.0

Exhibition halls or fairs	3.0
Diagnostic rooms	3.5
Classrooms and laboratories	3.5
Hospital rooms	4.0
Indoor enclosures not described in this list	4.0
Common zones	4.0
Warehouses, archives, technical rooms and kitchens	4.0
Parking	4.0
Sport facilities	4.0
Transport stations	5.0
Supermarkets, hypermarkets and department stores	5.0
Libraries, museums and art galleries	5.0
Common areas, non-residential buildings	6.0
Malls (excluding stores)	6.0
Hotels and restaurants	8.0
Religious buildings	8.0
Halls, auditoriums and multipurpose rooms and convention facilities, leisure and entertainment, meeting rooms and conference rooms	8.0
Shops and small business	8.0
Hotel rooms, hostels, etc	10.0
Premises where light level exceeds 600 lux	2.5

E value (lux) is established by the regulation UNE12462_1 where required lighting levels are established and it can be determined by the following expression:

$$E_m = (\mathrm{n} \cdot \Phi_L \cdot \eta \cdot f_m)/(\mathrm{S} \geq E_{tables})$$

Where,

$E_{tables} = E_{UNE}$

η : Using coefficient (from the premise's k index and from the reflectance values of walls and ceilings)

f_m : Maintenance factor

Φ_L : Flux luminaire

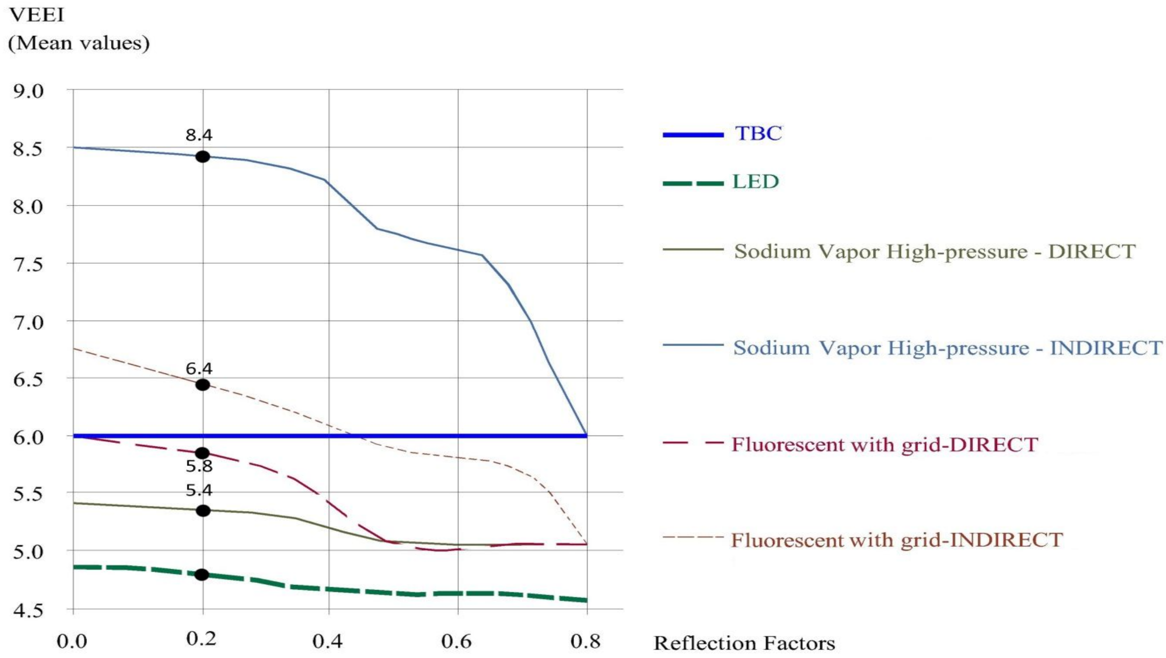
Table 9. *k index and lighting system*

Lighting system	k index in the premise
Direct, semi-direct, direct-indirect and general diffuse lighting	k = (a·b) / (h·(a+b))
Indirect and semi-indirect lighting	k = (3·a·b) / (2·(h+0.85)·(a+b))

a, length of the premise
b, width of the premise
h, height of the premise

In figure 5 can be seen the economic saving in Watts per square meter to produce 100 lux, which can be obtained by LED lighting in comparison with another type of luminaries.

It can be seen that for a reflection factor in the walls of 0.2 of LED lighting it is obtained a VEEI value of approximately 4.8. With the other luminaries VEEI value is increased in a 12.5% (5.4), 21% (5.8), 33% (6.4) and 75% (8.4).



The lamp that stands out most regarding power is the one that also exceeds the energy efficiency standards: power per m^2 to produce 100 lux. Therefore, the logical decision would be to assume that the luminary replacement, which requires a minimal work, becomes a solution of large energy savings throughout the time (the saving is not immediate), without diminishing the minimum required power.

D. Energy certification in buildings

From July 2007, TBC obligates to certify buildings energetically. It consists of a legal requirement that all new buildings must accomplish. From two years onwards it will be applied to existing buildings. Nearly 30% of primary energy consumption comes from buildings. This is why new European regulations focus on the energy consumption of constructions.

Regulations show classifications of new constructions according to their efficiency degree, the estimated consumption and associated CO2 emissions. Different categories go from the most efficient, A, to the less efficient, G, and B, C, D, E, F in between.

The objective of building certification is to encourage promoters to build more efficiently and cheer up building refurbishment to low energy consumption.

Thus, every building would get a Certificate of Energy Efficiency. This target has been included in both TBC and the regulation of thermal installations in buildings [14]. Nevertheless, at the moment it is only compulsory for new buildings, whereas it is considered a more urgent task its application in pre-existent buildings.

TBC indicates that several parameters must be included, within the architectural projects, which are difficult to control lately, instead of facing the problem in the other way round. As an alternative of limiting the global transference coefficient of buildings, it should limit the building energy consumption according to its use, location, floor area and others.

Whether it is considered that the final aim was the limitation of the energy demand, it would be possible to achieve low energy consumption from diverse and varied constructive solutions.

The main problem of energy efficiency regulations is that due to the fact that buildings are complex, when trying to model and compare them, it is easy to establish several simplifications. Therefore, in order to obtain the building rating two different methodologies have been proposed:

- The use of software such as LIDER and CALENER. Computer programs have so many limitations and eventually generate buildings without architectural values, as they are projected following standard solutions and rigid patterns concerning design.

- A simplified option, based on the accomplishment of a series of minimum values established in the TBC, could be followed but classes D or E are the ones obtained. Therefore, using this option the building would get a lower rating than using the other method.

It can be conclude that the established consumption must be limited.

IV. CONCLUSIONS

This paper does not look for illustrating through a complete study the numerous proposals that generate and adequate energy savings. On the contrary, it tries to exemplify how by means of small interventions savings could be high. They can be applied in many different building types and contribute to reduce the energy demand.

The current regulation must take them into consideration and act accordingly with the suggesting alternatives adjusted to the studied buildings.

As it is showed in the calculations, they demonstrate small solutions well implemented allow energy savings that should be considered in several energy regulations.

Some of the proposals are not practical, such as the fact of introducing insulation inside the air cavity of external walls. However, the most efficient solution would be replacing internal partitions by cardboard planes.

According to the Lighting Research Centre and the California Energy Commission: '*LEDs have distinctive features that offer the possibility for unique solutions that were not possible with conventional light sources. For example, the relative small size of LEDs allows for the creation of efficient low-profile luminaries that could become invaluable in applications where space is at a premium'. 'Light-emitting diodes (LEDs), a semiconductor-based light source has become rapidly a viable light source for general illumination applications'* [15].

The aim is to achieve what is currently in the spotlight: sustainability and energy saving. The essential points are:

- Energy saving
- Profitability
- Possibility of legislation, environment or social conditions

The classification of building types should be made regarding both the use and the possibility of making changes associated to refurbishment.

Understanding that these contributions are always in the case of existing buildings, in new buildings it is impossible to follow recommendations, since they must be taking from the beginning of the project idea.

The current regulation, therefore, should be more flexible regarding design, ensuring with a prior study of energy and economical savings associated to the construction volume, rather than requiring actions that not consider their operational capacity.

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REFERENCES

[1] Técnico, Bibliografía Básica Normativa General-Código. De La Edificación (CTE).
[2] "CTE. Historia", available at: http://www.codigotecnico.org/web/cte/historia/ (accessed 13 April, 2015)
[3] ALLEN, Edward. Como Funciona Un Edificio. *Editorial Gustavo Gili*, 1982.
[4] BRUNSGAARD, C., HEISELBERG, P., KNUDSTRUP, M., & LARSEN, T. S. (2012). Evaluation of the indoor environment of comfort houses: Qualitative and quantitative approaches. Indoor and Built Environment, 21(3), 432-451. doi:10.1177/1420326X11431739
[5] HALLIDAY, Sandy. *Sustainable Construction.* Routledge, 2008. 25-27
[6] HALLIDAY, Sandy. *Sustainable Construction.* Routledge, 2008. 38-42
[7] CLARK, William H.; and GÓMEZ, Claudio M. *Análisis y Gestión Energética De Edificios: Métodos, Proyectos y Sistemas De Análisis De Ahorro Energético.* MacGraw-Hill, 1998.
[8] UNE EN ISO 10 456:2001 Regulation. 9-15

[9] RODRÍGUEZ, José C. *Ahorro Energético En La Construcción y Rehabilitación De Edificios.* Thomson-Paraninfo, 2001.

[10] Advice Services. *Energy Efficiency in Traditional Buildings*, 2010.

[11] "External wall insulation in traditional buildings". Research Report. 2014. English Heritage. 17 available at: https://content.historicengland.org.uk/images-books/publications/external-wall-insulation-traditional-buildings/external-wall-insulation-in-traditional-buildings.pdf/ (accessed 12 April 2015)

[12] OGLEY, P., et al. Energy Efficiency in Historic Buildings-Insulating Solid Walls, 2010.

[13] "Energy Efficient Lighting" at: www.michigan.gov/documents/CIS_EO_Lighting_167401_7.pdf (accessed 13 April, 2015)

[14] Reglamento de Instalaciones Térmicas en Edificios. Rite. *Normativa Aprobada El*, 2007, vol. 31.

[15] Lighting Research Program Project 2.3 Low-Profile Led Luminaries, 2007.